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AERODYNAMICS OF SEEING ON LARGE TRANSPORT AIRCRAFT

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I. BACKGROUND

The successful operation of large transport aircraft containing optical surveillance systems, such as current those of interest in astronomy, requires the formation of high quality images. The quality of these received images from radiation of wavelengths from the very short visible to the far infrared is of interest. Because of the desire to receive both near and far infrared signals, material windows (even of very high quality) are not considered because of their degradation to these signals. Thus, open cavities are usually perceived to contain the telescope or sensor systems in question. Within these open cavities in flight, two major issues influence the overall performance of the systems. The first is the mechanical environment in which the optical system must perform in flight. This environment includes the vibration input to the optical system through the aircraft motions, as well as unsteady pressure variations imposed on the sensors or telescopes that exist as a result of aerodynamic flow over and within the open cavity. Unsteady pressure loads might conceivably produce deflections, or unsteady mis-alignments, of optical elements placed within the cavity, and hence degrade the quality of the image. Normally, various aerodynamic devices are chosen to minimize such aero-mechanical effects. The resulting aerodynamic flow fields may have an adverse impact on the optical systems through the production of unwanted index-of-refraction fluctuations that can produce distortions of optical wavefronts. The latter subject is commonly known as aero-optics, and is of primary interest in the current study.

Efforts were undertaken in the present study to obtain a set of data that examined the level of turbulence and the scale sizes in the shear layer existing over the fence quieted cavity on the NASA-Ames Kuiper Airborne Observatory (KAO). These data were to be taken during the present study and compared with data taken from previous wind tunnel experiments, for which both aerodynamic and direct optical measurements had been made. These data are presented in references 3 and 4. The data obtained during the present study were presented in reference 1 and were discussed in light of their impact on the quality of optical images, that is, "seeing" through the shear layer. In addition, reference 1 presented scaling relationships that allow optical data obtained in one aerodynamic environment to be estimated for another one at perhaps different Mach numbers, scale sizes or aircraft configurations.

II. SUMMARY OF RESULTS OBTAINED UNDER THE PRESENT GRANT

The primary effort completed under the present grant was the completion of a major in-flight test of the optical properties of an actual shear layer over an open cavity on a large body aircraft. The aircraft was the KAO, which is a modified C-141 aircraft. A large open cavity is placed in the front of the aircraft with a 36" diameter primary mirror telescope operating in the cavity. Aerodynamic data were obtained and index-of-refraction variations were inferred from the aerodynamic data. The references given in reference 1 detail this procedure. The data were obtained at flight Mach numbers of 0.7 and 0.8, and it was found that RMS wavefront errors of approximately 0.21 to 0.23 microns were found. These are variations of the wavefront that could be expected to occur to a parallel wavefront passing through the turbulence associated with the shear layer over the open cavity. The density fluctuations and the scale lengths over which those density fluctuations occur are detailed in reference 1. With the above quoted wavelength variations, one can see that these values are of the order of 1/4 to 1/2 a wave variation for visible radiation.

In terms of optical parameters, these wavefront variations cause an increase in the minimum spot size in the focal plane. The size of this image in the focal plane is of interest in terms of seeing in that it represents the minimum diameter of a point source perceived by an ideal telescope. For the above quoted wavefront errors, the spot size observed in the focal plane range from approximately 8 to 9 microradiens, or approximately 1.5 to 2 arc-seconds at a Mach number of 0.8, while at the lower Mach number of 0.7 these image sizes were found to range between about 6 and 10 microns depending on operational altitude and the position of the porous fence located ahead of the open cavity to prevent its resonance. These latter figures correspond to a range between about 1 and 2 arc-seconds.

Data were shown in both references 1 and 2 from experiments taken in wind tunnel studies on smaller scale models and in another flight experiment and compared with the data obtained in the present Grant. Scaling relationships were shown for both the width of the shear layer and the scale sizes expected to occur in the shear layer. A linear scaling relationship was shown for both the shear layer width and shear layer scale sizes.

The data inferred from the aerodynamic measurements were found to be in general agreement with those values produced in the same flight experiment measured by direct optical means. On the basis of the aerodynamic scaling information and the agreement between the direct and inferred optical performance, reference 1 presented scaling information showing the variation of focal plane spot size as a function of radiation wavelength for both the KAO and a hypothetical aircraft scaled to be three times as large as the KAO's aperture.

Reference 2 presented data from another series of flight experiments carried out under the current Grant related to the aero-mechanical environment in the KAO. The effects of the aerodynamic flow on accelerations of the various optical elements located on the telescope within the open cavity were investigated in flight. It was found that during normal operations of the KAO, accelerations of less than 0.01 g were observed, even on the secondary mirror. These seemingly small accelerations, however, produced substantial angular motions of the telescope's secondary mirror, even when it was held in a relatively rigid mount. These motions were shown in reference 2 to result from the aero-mechanical effects in flight when the cavity door was open. The motions of the secondary mirror, when translated through the magnification and f number of the telescope, amount to up to another 1 arc-second of increase in image size due to unsteady focus motions.

III. REFERENCES

1. Rose, W.C.: Aerodynamics of Seeing on Large Transport Aircraft, Progress Report, 1 December 1985 - 31 May 1986 prepared under NASA Grant NCC 2-382. Available from NASA STIF, Box 8757, BWI MD 21240.

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